**Chemical energy and gravitational energy**

Objective:

Students will be able to use the concept of chemical equilibrium to explain how increasing CO2 in atmosphere and increasing global temperatures may have an effect on the acidity of the oceans.

In this exercise we will compare chemical and gravitational energy. This comparison was introduced in lesson 19.

Causal Principles:

2. At equilibrium, energy is balanced and no net change occurs.

3. At equilibrium, there is a fixed concentration of atoms and molecules in different phases or materials.

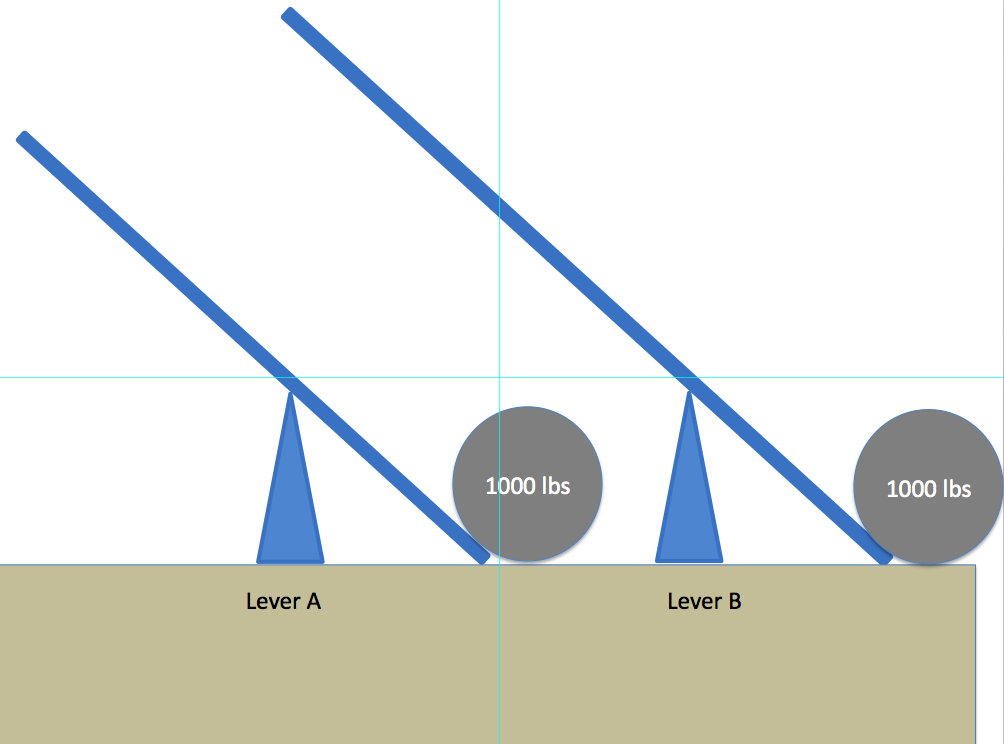
6. Change in temperature causes molecules to move faster or slower.

8. When molecules move faster, it is easier to break bonds.

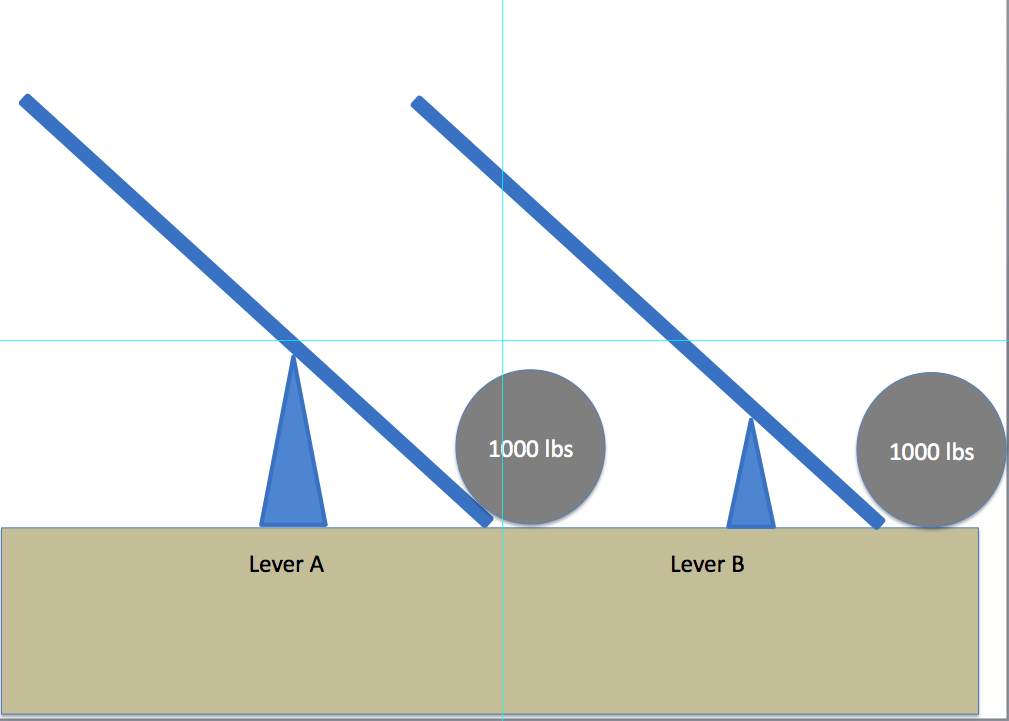
**Gravitational Equilibrium.**

A teeter totter or see saw is a good way to describe gravitational energy and the concept of equilibrium. In case you never played on a see saw or have forgotten the experience, let’s review how they work. To do that, we will review what happens with a lever. You’ll see why we start with a lever soon.

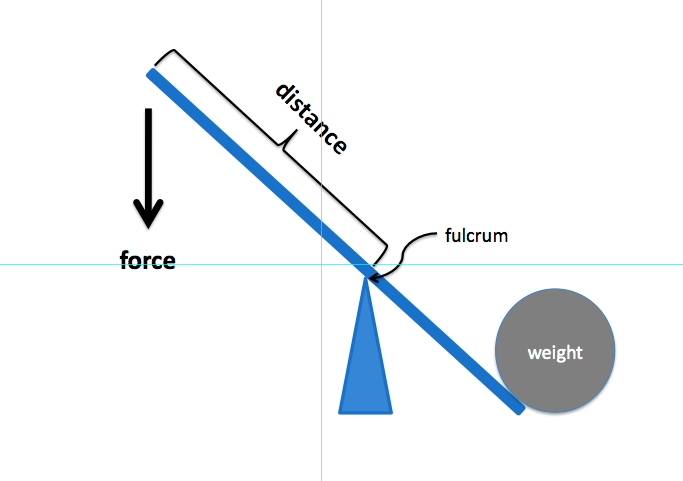
Let’s begin by posing this question. Figure 1 shows a 1000 pound ball we want to move. Will it be easier to move the weight with lever A or lever B. By easier, we mean will we need to exert less force when moving lever A or lever B. Hopefully, you recognize that lever B, the longer lever, be easier to move.



Let’s look at this another way. In this case the levers are the same length but we’ve

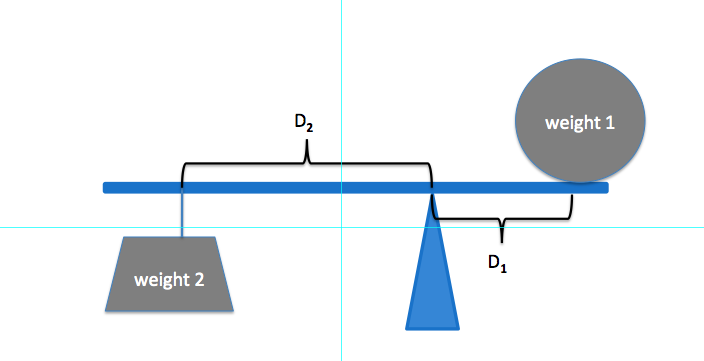


*moved the base* on which the lever rotates. Which will do a better job, A or B? Again the answer is lever B. Can you figure out what is the common thread that makes lever B the better choice in both cases?

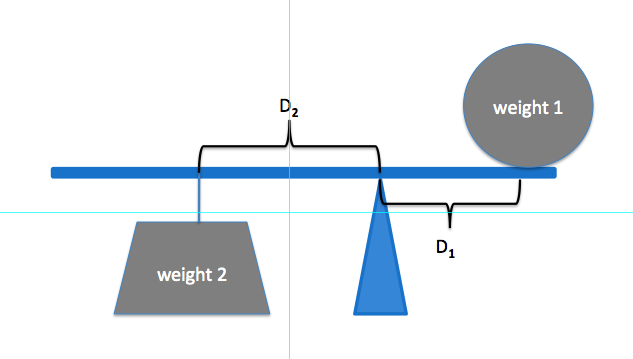


The distance from the end of the lever to the point of rotation (fulcrum) is the key element. More than 2000 years ago, Archimedes said, “Give me a long enough lever and I can lift the Earth.”

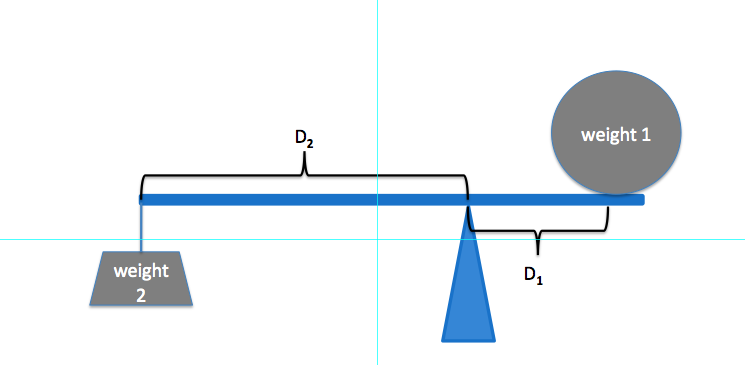
Now lets start to apply a force to the lever. Clearly there is some amount of force we can apply to the lever that will raise weight. Most of us can imagine, from personal experience that a balance can be established where weight 1 times distance 1 will result in a force that equals weight 2 times distance 2.



The balance can be altered by increasing weight 2 and shortening distance 2,



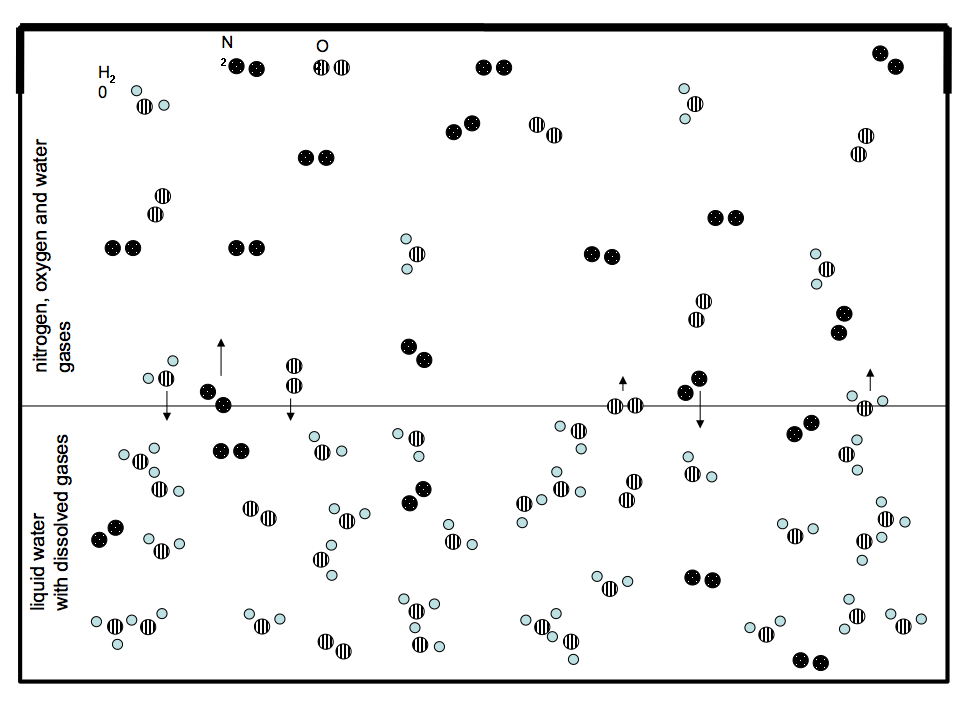
or by increasing distance 2 and decreasing weight 2.



Each configuration of weights and distance that result in a balance at the fulcrum is a situation that we refer to as equilibrium. At equilibrium, the force on one side of the fulcrum equals the force on the other. We refer to this as gravitational equilibrium because both weights are pulled down by gravity.

**Chemical Equilibrium**

Chemical equilibrium refers to the situation in which two different arrangements of the same atoms are balanced. For example, if water is placed in a sealed container with some air space. Look at the figure below to see a molecular model of what is in the sealed jar.



There are only three molecules that concern us; water (H2O), oxygen gas (O2) and nitrogen gas (N2). Nitrogen and oxygen are the two most abundant gases in our atmosphere. These gases are in the atmosphere and a small amount is dissolved in the water. Water is in two phases: liquid water and gaseous water in the atmosphere. For now, we’ll focus on the liquid and gaseous water. Notice that there are molecules of gas in the water and the atmosphere. Also notice that the concentration of gaseous water molecules is much less than the concentration of water molecules in the liquid water. If the sealed jar is held at a constant temperature, eventually there will be a fixed concentration of water vapor in the atmosphere overlying the liquid. This concentration of water vapor is said to be in equilibrium with the liquid water.

One way to change the equilibrium would be to change the temperature of the sealed container. What would happen if the temperature of the container were increased or decreased? We know from our experience that the amount of water vapor would be higher at higher temperatures and lower at lower temperatures. This makes sense to us when we remember that temperature is simply a measure of the average speed of molecules. When the temperature of water increases, then more molecules can escape from the liquid and enter the vapor phases.

Although at equilibrium there is no net change in the amount of liquid water and water vapor, there is always movement of the water molecules. Some molecules move from the liquid to the vapor while an equal number move from vapor to liquid. To campure this idea, some people like to use the phrase **dynamic equilibrium**.

Recall that all movement and change requires energy. Also recall that energy is required to break bonds and energy is released when bonds form. We define dynamic equilibrium as a situation in which the amount of energy used to break bonds is equal to the amount of energy being returned through the formation of new bonds.

The idea of chemical equilibrium is often expresses by an equation. Many people don’t like equations but if you’ll bear with me, I think you’ll see a simplicity and usefulness to them. We’ll begin with equilibrium between liquid water and water vapor. The chemical equation is simply:

H2O (liquid) H2O (vapor) (equation 1)

The equation states two things. First, notice the arrows going both ways. 1) This means that, at equilibrium, the amount of water changing from liquid to vapor is equal to the amount of water changing from vapor to liquid. 2) It also means that at equilibrium, the chemical potential energy of the liquid water is equal to the chemical potential energy of the water vapor.

Let’s imagine we squirt some water vapor into the sealed container of liquid water already in equilibrium with water vapor. What would happen? First let’s think about statement 1 above. For this statement to remain true some of the water vapor we added to the container must turn in to liquid water. Now let’s think about the second statement. If we only add water vapor, then we’ve increased the chemical potential energy of the water vapor but we’ve not changed the chemical potential energy of the liquid. To return to equilibrium, some of the water vapor must convert to liquid water. So both statement 1 & 2 above lead us to the same conclusion.

Now let’s increase the temperature of the container. I’m sure you know what happens. More of the liquid water will convert to water vapor. At the higher temperature, a new equilibrium will form. At this new equilibrium, there will be more water vapor and less liquid water than at the lower temperature.

Next we’ll add carbon dioxide gas to the sealed vessel containing liquid water and water vapor, carbon dioxide gas.

H2O (liquid) + CO2 (gas in water) H2O (vapor) + CO2 (gas) (equation 2)

At equilibrium some of the carbon dioxide gas will be in the gas above the liquid water and some will be dissolved in the water. Following the same reasoning we did with water, what do you predict will happen if we add more CO2 gas to the sealed container? Some of the additional carbon dioxide gas will dissolve in the water until a new equilibrium is reached.

The carbon dioxide gas dissolved in water reacts with the water molecules to form yet another equilibrium in which there is an energy balance between water and the dissolved carbon dioxide gas with two other molecules, hydrogen ions and bicarbonate ions. The equation that describes this reaction is

H2O (liquid) + CO2 (gas in water) H++ HCO3- (equation 3)

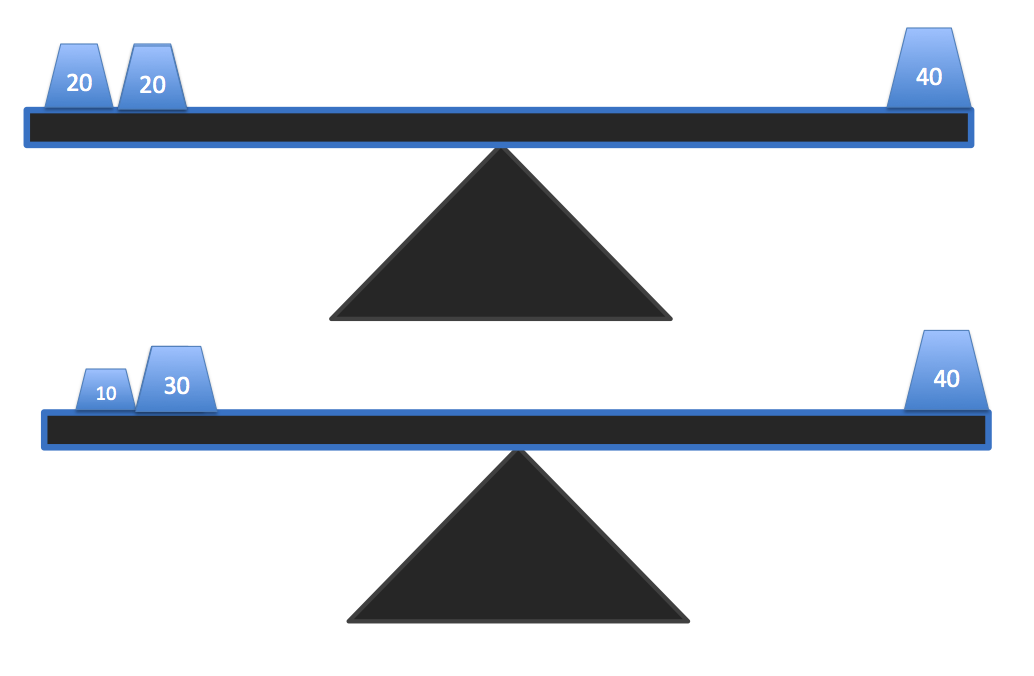
H+is the hydrogen ion. HCO3 – is the bicarbonate ion.

**An Inference about Chemical Equilibrium**

This exercise started with a discussion of gravitational equilibrium because we can use that system as an analog for chemical equilibrium. We’ll try this out with the following question. If H2O (vapor) + CO2 (gas) are in equilibrium with H2O (liquid) + CO2 (gas in water) and H2O (liquid) + CO2 (gas in water) is in equilibrium with H++ HCO3-, can we infer that H2O (vapor) + CO2 (gas) are in equilibrium with H++ HCO3- ? If we trust the analogy with gravitational equilibrium, the answer is yes.

Here’s the gravitational energy analog. Consider two balances as shown below.

If the two 20 pounds weights are in equilibrium with the 40 pound weight, and the 10 and 30 pound weights are in equilibrium with the 40 pound weight, then the two 20 pound weights are in equilibrium with 10 and 30 pound weights. This simple example can be translated to the question about chemical equilibrium.



Let’s try it.

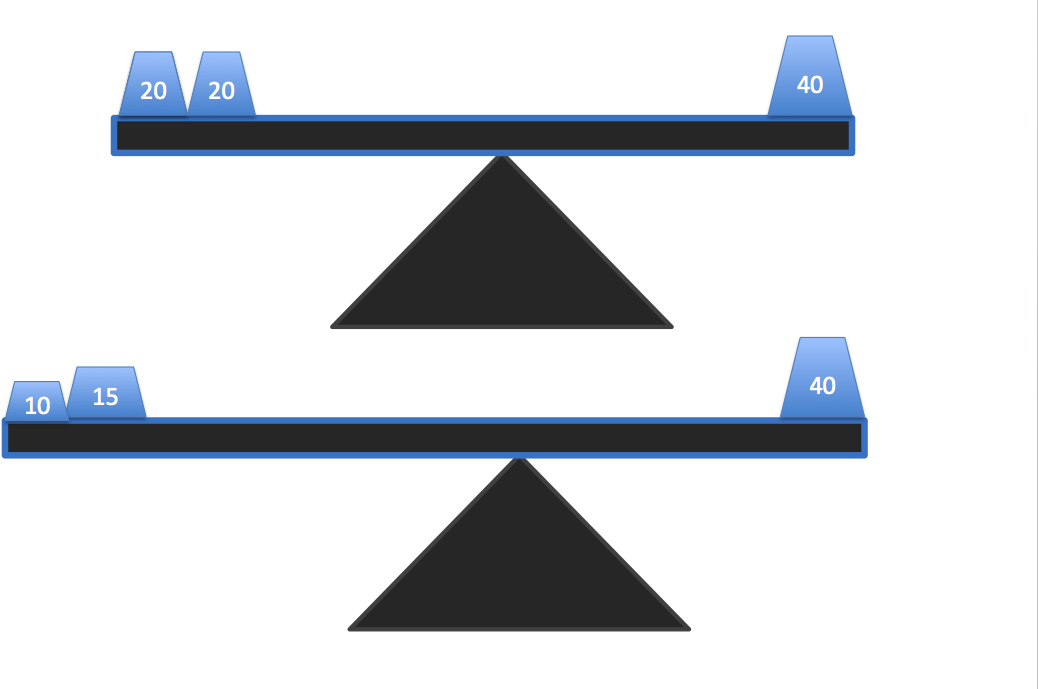
**Alignment of features and relationships**

Complete the table below by filling in features in the chemical reaction that align with the features in the gravitational equilibrium.

|  |  |
| --- | --- |
| Gravitational | Chemical |
| Two 20 lbs weights |  |
| 10 + 30 lbs. weights |  |
| 40 lbs. weight |  |

The common relationship throughout this comparison is assuming that gravitational and chemical equilibrium have been reached.

Now let’s look at another gravitational balance that can tell us something about chemical equilibrium. Remember, we can change gravitational equilibrium by changing the distance between weights and a fulcrum as shown below.



Changing the gravitational equilibrium by changing the length of the fulcrum is similar to changing\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ of a chemical reaction. Hopefully, you wrote the word temperature in the blank. Please complete the table below by comparing features in gravitational equilibrium to features in chemical equilibrium.

**The role of temperature in chemical equilibrium**

We’ll start thinking about the role of temperature in chemical reactions by recalling two of our basic principles.

Principle 6: Change in temperature causes molecules to move faster or slower.

Principle 8: When molecules move faster, it is easier to break bonds.

These principles help us explain a few simple observations.

1) When liquid water is heated, more water vapor forms.

2) Cold water can dissolve more carbon dioxide than hot water.

3) Hot water can dissolve more table salt (NaCl) than cold water.

In the table below explain why the relationships listed in columns 1& 2 are similar.

|  |  |  |
| --- | --- | --- |
| Column 1 | Column 2 |  |
| Hot water dissolves more salt than cold water | Hot water creates more water vapor than cold water |  |
| Hot water creates more water vapor than cold water | Hot water releases more dissolved CO2 than cold water |  |
| If a hot solution in equilibrium with salt is cooled, more solid salt will form. | If hot water in equilibrium with water vapor is cooled, more liquid water will form. |  |

**General Alignment of Gravitational and Chemical Energy**

There are to four ways to alter a gravitational equilibrium; increase weight, decrease weight, increase distance to fulcrum and decrease distance to fulcrum. List four similar ways to alter chemical equilibrium between a liquid and a gas in a container by completing the table below.

|  |  |
| --- | --- |
| **Gravitational** | **Chemical** |
| Increase weight |  |
| Decrease weight |  |
| Increase distance to fulcrum |  |
| Decrease distance to fulcrum |  |

**Assessment:**

Carbon dioxide emissions are presently making the oceans more acidic. The chemistry that shows this is simple and depicted in the equation below.

CO2 + H2O HCO3- + H+ (equation 4)

HCO3- is an ion called bicarbonate. H+ is the hydrogen ion. The acidity of a sea water is a measure of the amount of hydrogen ions in the water.

We do not have time in this course to describe the biological effects of ocean water acidity but those of you who have ever had a fish tank may recall that you added chemicals to the tank to prevent it from becoming too acid. The reason that your tank needed this treatment is that organic matter (mostly fish feces) decay in the bottom of the tank producing CO2.

1) Using the concept of chemical equilibrium, explain why increasing carbon dioxide in the atmosphere may lead to increased acidity of water.

2) Using the concept of chemical equilibrium, explain why increasing global temperature may lead to decrease in acidity of sea water.